



NASA's Lunar Science Program

*Presentation at the
GSFC Lunar Exploration Science Working Group*

James L. Green
Director, Planetary Science Division

February 15, 2008



Outline

- Science Mission Directorate FY09 Budget Overview
- Planetary Science Division Funding
- Lunar Science Activities



SMD'S CROSS-CUTTING FY09 BUDGET OBJECTIVES



- Focus a larger fraction of SMD's resources on Earth Science
- Increase space science R&A/MO&DA to get better value from our flight missions
- Increase space science suborbital research programs to foster PI training, technology demonstration, and accomplish more science
- Accelerate the execution of mission queues in all four of SMD's science theme areas
- Support NRC Decadal Survey priorities
- Initiate an SMD lunar robotic science program



MAJOR FY09 BUDGET CHANGES

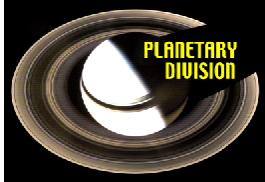


- \$600M transfer from Space Science to Earth Science over 5 years for their new Decadal missions
- Six new FY09 missions starts: more than in the past four budgets combined; at least one per SMD science area:
 - Earth Science: IceSat II & DESTINY (2012, 2015 launches)
 - Astrophysics: JDEM (launch in 2014)
 - Heliophysics: Solar Probe Plus (launch in 2015)
 - Planetary: Outer Planets Flagship (launch in 2016/2017) and lunar science orbiter (launch in 2010/2011)
- Substantial increases in astrophysics, heliophysics, and planetary science R&A/MO&DA
- Increased budgets for suborbital rockets and balloons

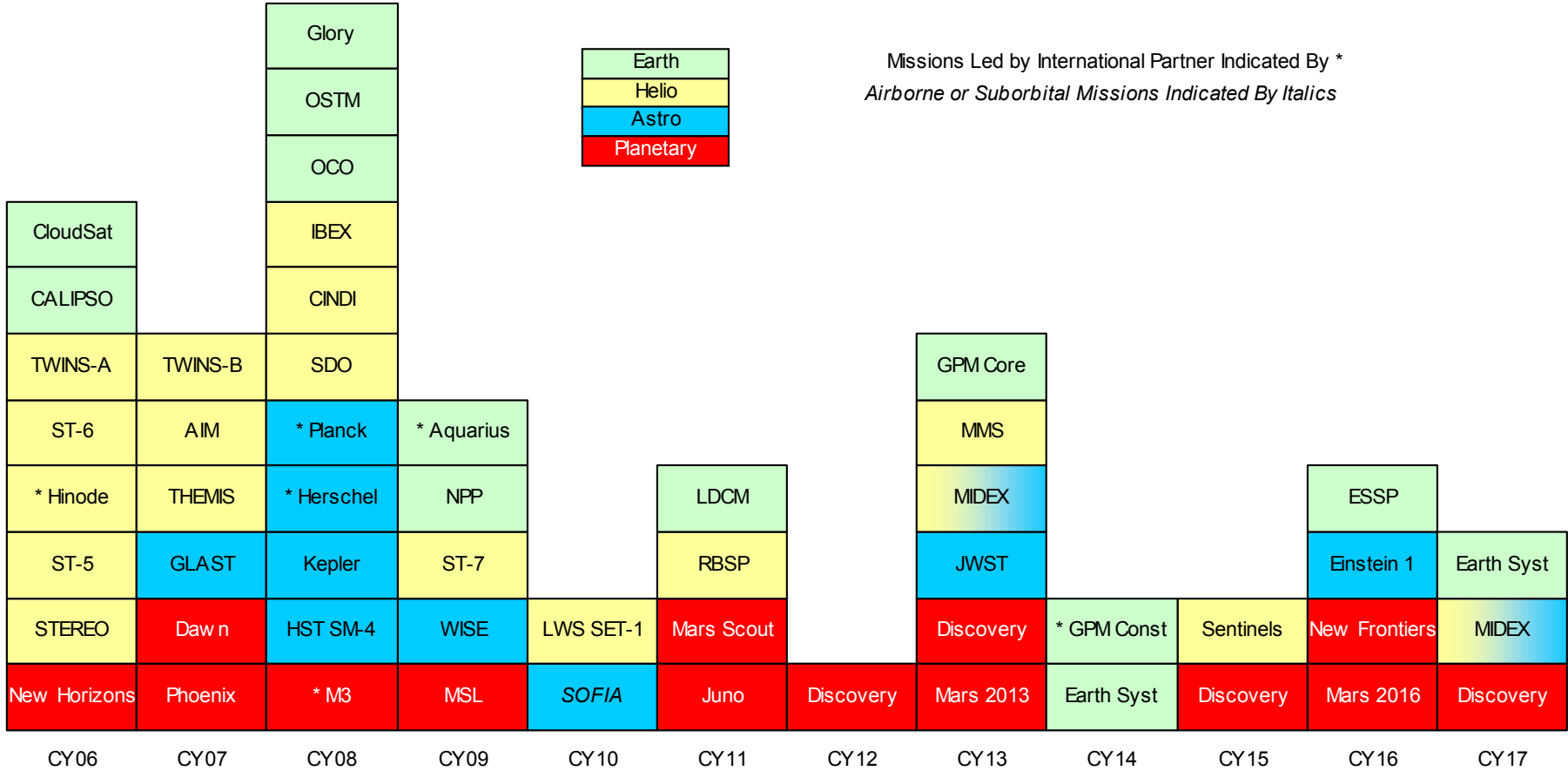
Funding for new starts and R&A increases came from:
internal transfers, efficiencies, out-year mission ops savings,
and re-phrasings for MMS and Scout.



SMD'S FLIGHT PROGRAM: JANUARY 2007



Launches by Calendar Year

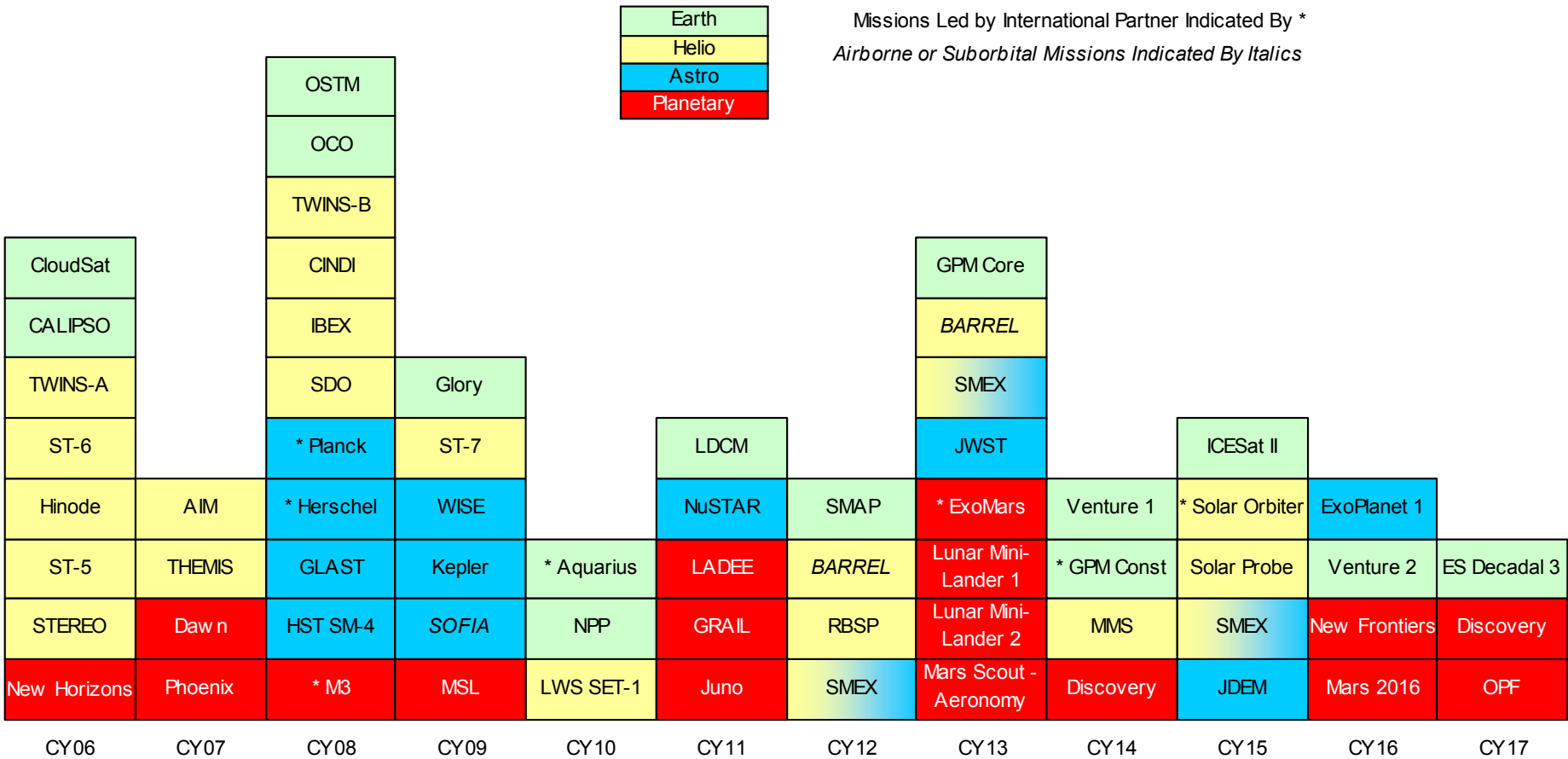




SMD'S FLIGHT PROGRAM: JANUARY 2008



Launches by Calendar Year



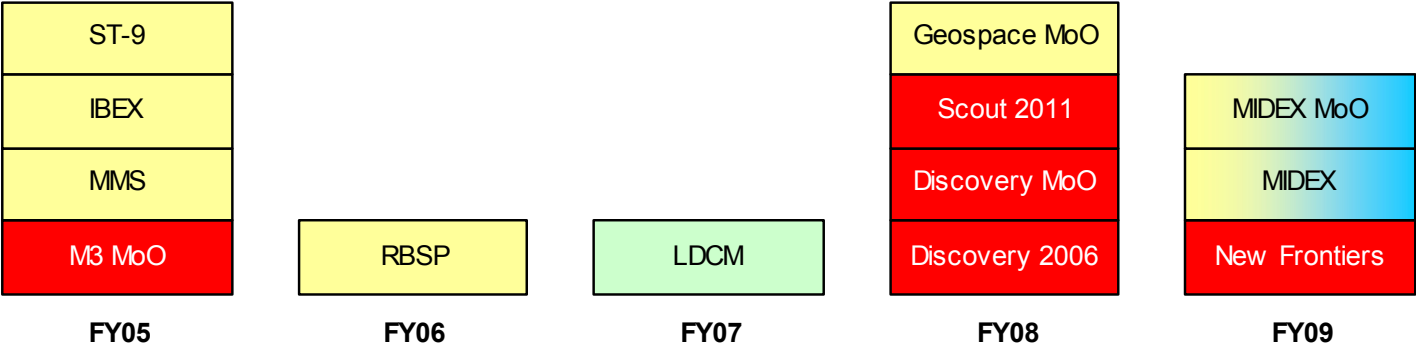


NEWLY STARTED MISSIONS: FY08 BUDGET



New Starts Defined as a Phase A Start Year or Final Downselect Year,
Whichever is Later.

Earth Science
Heliophysics
Astrophysics
Planetary

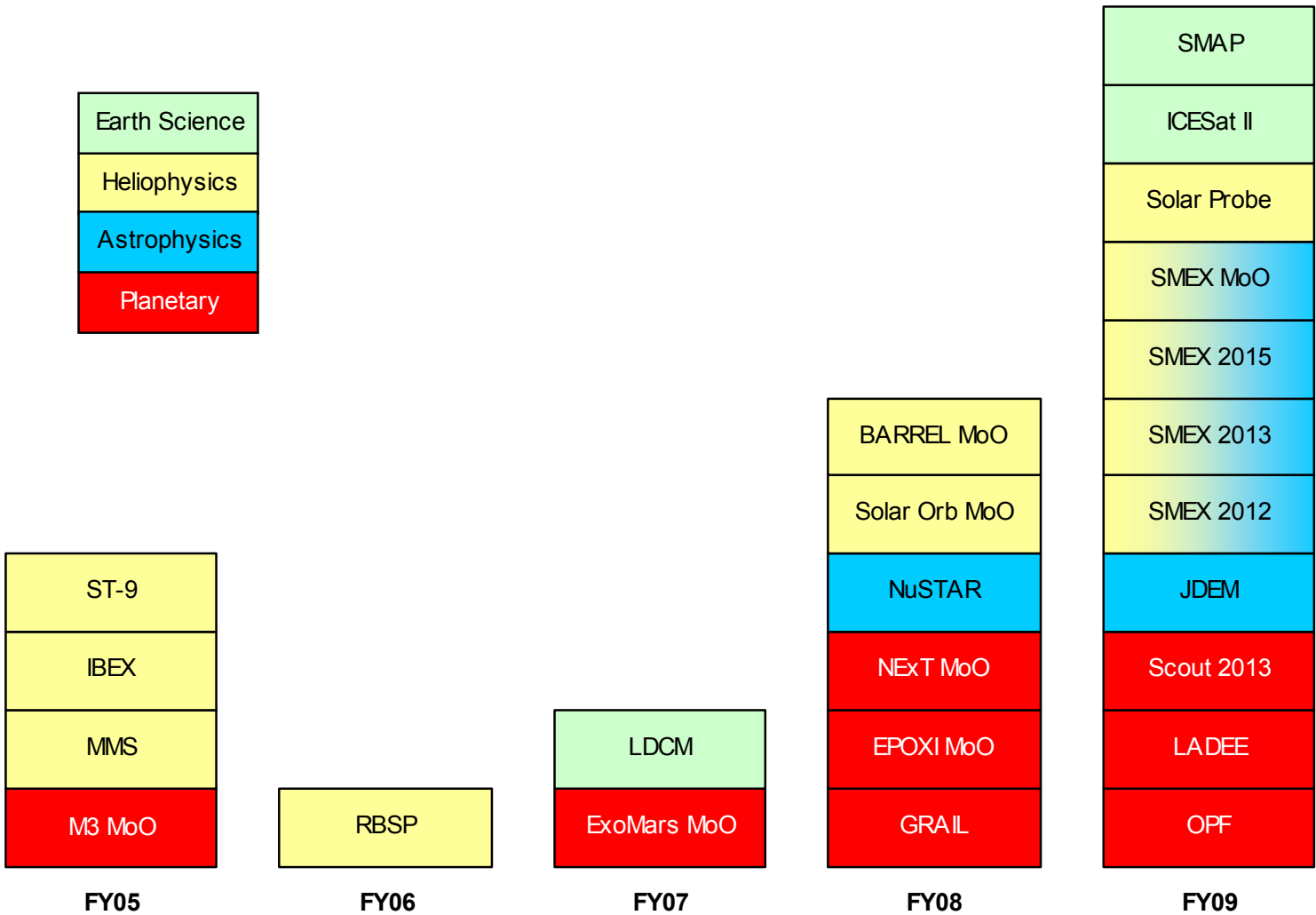


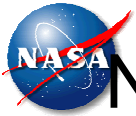


NEWLY STARTED MISSIONS: FY09 BUDGET



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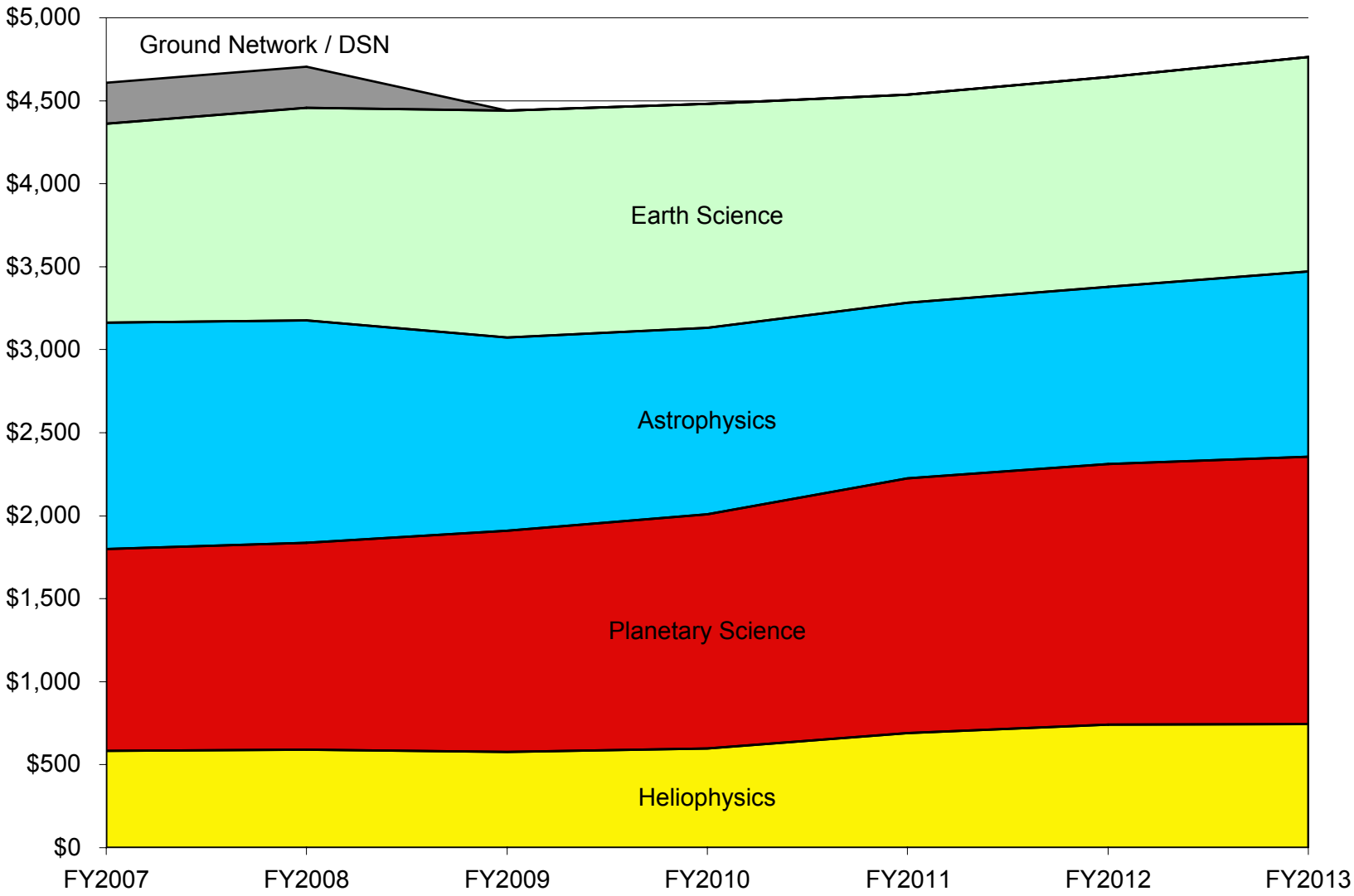
NASA PRESIDENT'S BUDGETS: FY09-FY13



	FY2007	FY2008	FY2009	FY2010	FY2011	FY2012	FY2013
<u>Total NASA</u>	<u>\$16,231.0</u>	<u>\$17,300.5</u>	<u>\$17,610.7</u>	<u>\$18,022.9</u>	<u>\$18,457.0</u>	<u>\$18,901.6</u>	<u>\$19,355.4</u>
<u>Science</u>	<u>\$4,609.9</u>	<u>\$4,706.2</u>	<u>\$4,441.5</u>	<u>\$4,482.0</u>	<u>\$4,534.9</u>	<u>\$4,643.4</u>	<u>\$4,761.6</u>
Earth Science	\$1,198.5	\$1,280.3	\$1,367.5	\$1,350.7	\$1,250.9	\$1,264.4	\$1,290.3
Planetary Science	\$1,215.6	\$1,247.5	\$1,334.2	\$1,410.1	\$1,537.5	\$1,570.0	\$1,608.7
Astrophysics	\$1,365.0	\$1,337.5	\$1,164.5	\$1,122.4	\$1,057.1	\$1,067.7	\$1,116.0
Heliophysics	\$583.7	\$590.9	\$575.3	\$598.9	\$689.4	\$741.2	\$746.6
DSN / Ground Network	\$247.2	\$250.0					
Aeronautics Research	\$593.8	\$511.7	\$446.5	\$447.5	\$452.4	\$456.7	\$467.7
Education	\$114.1	\$137.9	\$112.1	\$122.7	\$120.4	\$120.4	\$120.4
<u>Exploration Systems</u>	<u>\$2,837.6</u>	<u>\$3,143.0</u>	<u>\$3,500.5</u>	<u>\$3,737.7</u>	<u>\$7,048.2</u>	<u>\$7,116.8</u>	<u>\$7,666.8</u>
Constellation Systems	\$2,114.7	\$2,471.9	\$3,048.2	\$3,252.8	\$6,479.5	\$6,521.3	\$7,080.5
Advanced Capabilities	\$722.9	\$671.1	\$452.3	\$484.9	\$568.7	\$595.5	\$586.3
<u>Space Operations</u>	<u>\$5,093.5</u>	<u>\$5,526.2</u>	<u>\$5,774.7</u>	<u>\$5,872.7</u>	<u>\$2,900.1</u>	<u>\$3,089.9</u>	<u>\$2,788.5</u>
Space Shuttle	\$3,295.3	\$3,266.7	\$2,981.7	\$2,983.6	\$95.7		
International Space Station	\$1,469.0	\$1,813.2	\$2,060.2	\$2,277.0	\$2,176.4	\$2,448.2	\$2,143.1
Space and Flight Support (SFS)	\$329.2	\$446.3	\$732.8	\$612.1	\$628.0	\$641.7	\$645.4
<u>Cross-Agency Support</u>	<u>\$2,949.9</u>	<u>\$3,242.9</u>	<u>\$3,299.9</u>	<u>\$3,323.9</u>	<u>\$3,363.7</u>	<u>\$3,436.1</u>	<u>\$3,511.2</u>
Agency Management and Operations	\$971.2	\$830.2	\$945.6	\$945.5	\$939.8	\$950.5	\$961.3
Institutional Investments	\$223.8	\$319.7	\$308.7	\$331.7	\$335.9	\$330.4	\$338.3
Congressionally Directed Items		\$80.0					
Center Management and Operations	\$1,754.9	\$2,013.0	\$2,045.6	\$2,046.7	\$2,088.0	\$2,155.2	\$2,211.6
Inspector General	\$32.2	\$32.6	\$35.5	\$36.4	\$37.3	\$38.3	\$39.2



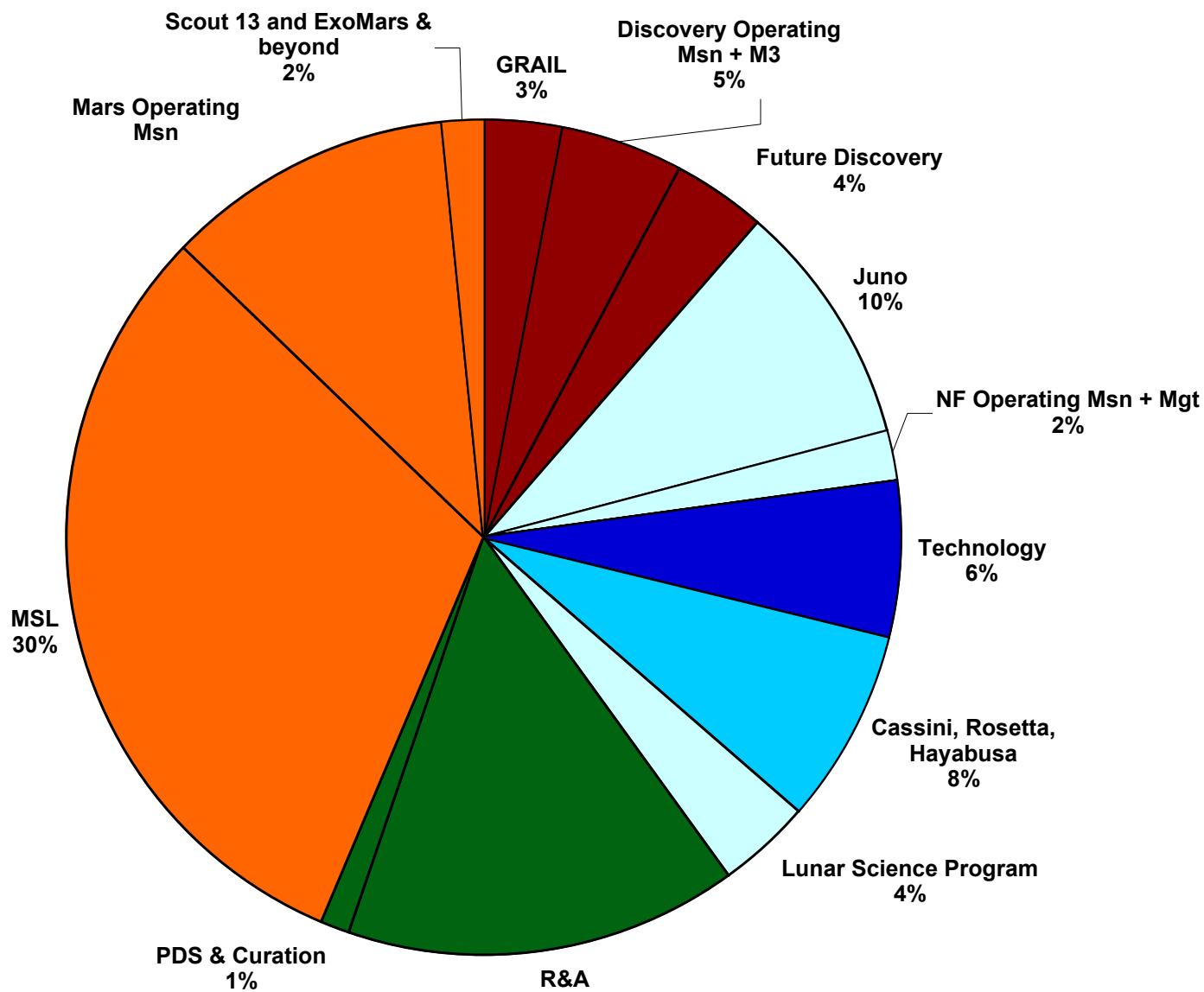
BUDGET BY SCIENCE THEME





Planetary Division

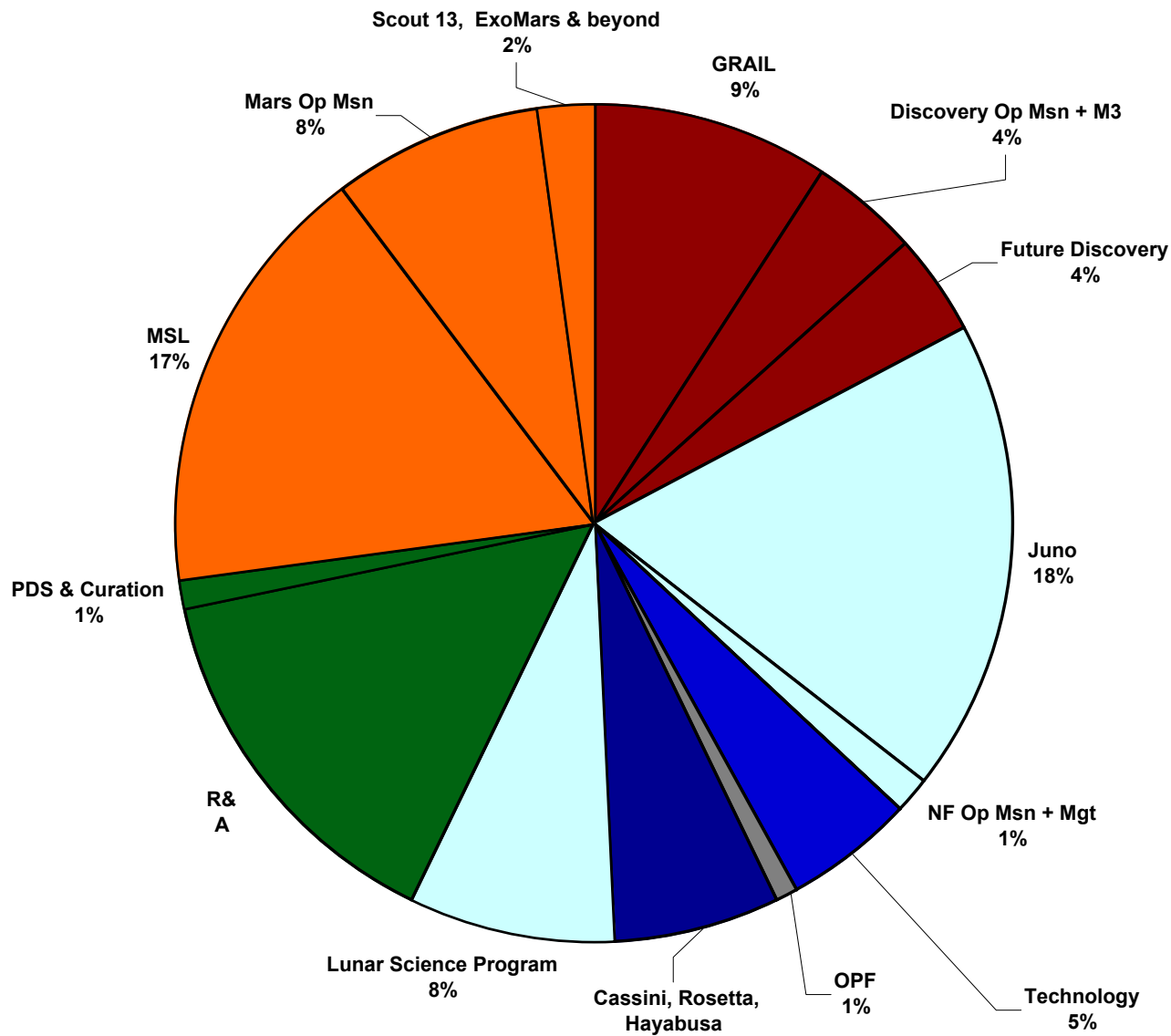
FY 2008 "Enacted" Budget, \$1158M





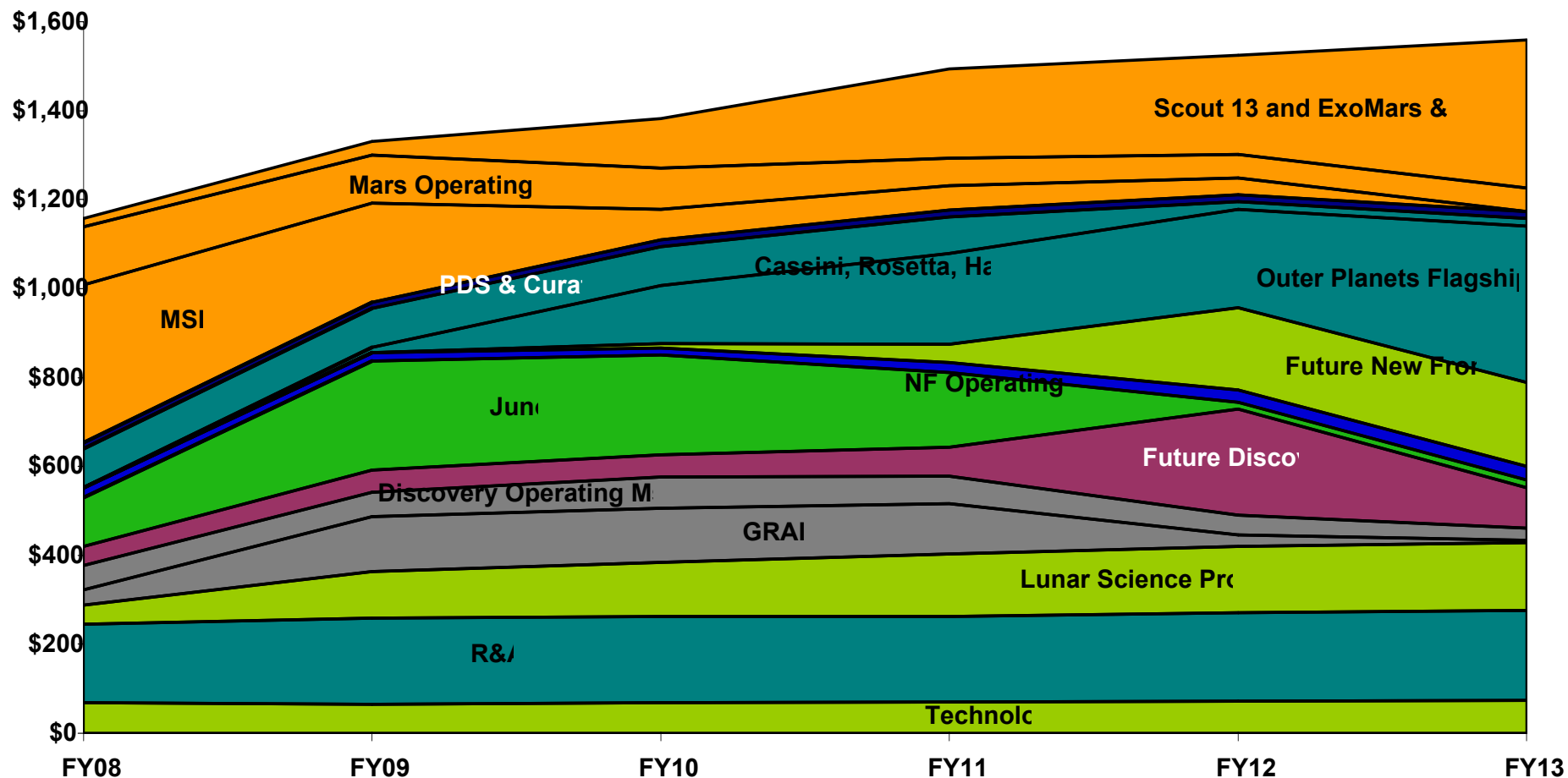
Planetary Division

FY09 President's Budget, \$1330M





Planetary Division FY 2009 Budget (\$M)





What Changed, What's the Same



What Changed:

- Initiates an Outer Planets Flagship (OPF) to establish a balance between inner and outer solar system exploration.
- Augments and enhances R&A to return more results from Planetary missions.
- Discovery Program: Includes the recently selected MoOs (EPOXI and Stardust-NExT), adds Aspera-3 2nd extension (ESA/Mars Express), and selected GRAIL.
- Preserves critical ISP work FY08 thru FY10, but deletes outyear activities in favor of more critical R&A and RPS enhancements.
- Completes the Advanced Stirling RPS development and prepares for flight demonstration.
- Mars Scout 2011 delayed to 2013 due to conflict of interest discovered during proposal evaluation.
- Redirects the Mars Program to focus on Mars Sample Return (MSR)
- Expands US participation on the ESA/ExoMars mission by funding the potential selection of BOTH candidate U.S. instruments and EDL support.
- Lunar Science Research augmented to include a series of small lunar spacecraft.

What's the Same:

- Discovery Program: MESSENGER, Dawn, Mars Express/Aspera-3, Chandraayn/MMM
- New Frontiers Program: Juno and New Horizons
- Mars Program: Odyssey, MER, MRO, Phoenix, MSL
- Research Program: Lunar Science, PDS, ESA/Rosetta, JAXA/Hayabusa



Upcoming Opportunities

- Stand-Alone Mission of Opportunity Notification (SALMON) - Draft February with release in ~May
- New Frontiers AO 1st Quarter FY09
- Discovery FY09



Overview of Lunar Activities

- Lunar Missions and Instruments on Missions of Opportunity
- Focused Research & Analysis (R&A)
- NASA Lunar Science Institute
- Lunar Science Conference



Lunar Missions

LRO, LCROSS, Grail, LADEE, ILN
M³(Chandrayaan-1)

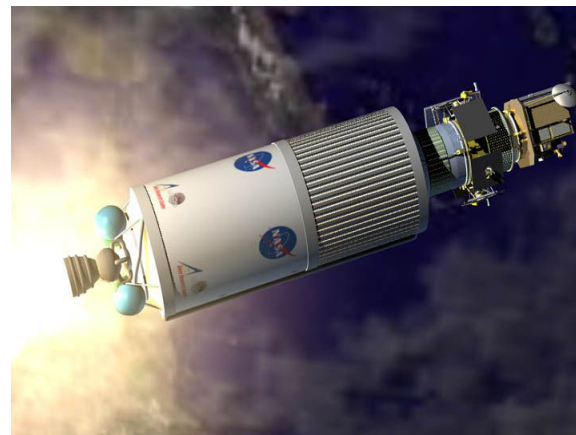


Lunar Reconnaissance Orbiter

(an Exploration Mission)



- LRO is NASA's first step in returning humans to the Moon.
- Focuses on identifying safe landing sites, locates lunar resources, and studies how the lunar radiation environment will affect humans.
- Will create the comprehensive atlas of the Moon's features and resources necessary to design and build the lunar outpost.
- The LRO mission will enable future exploration and also return lunar data that will significantly advance lunar and planetary science.
- LRO payload, comprised of six instruments and one technology demonstration.
 - *Launch date:* October 2008
 - Also carries LCROSS Lunar impactor as a secondary.
- After 1 year of operation will be transferred to the Planetary Science Division



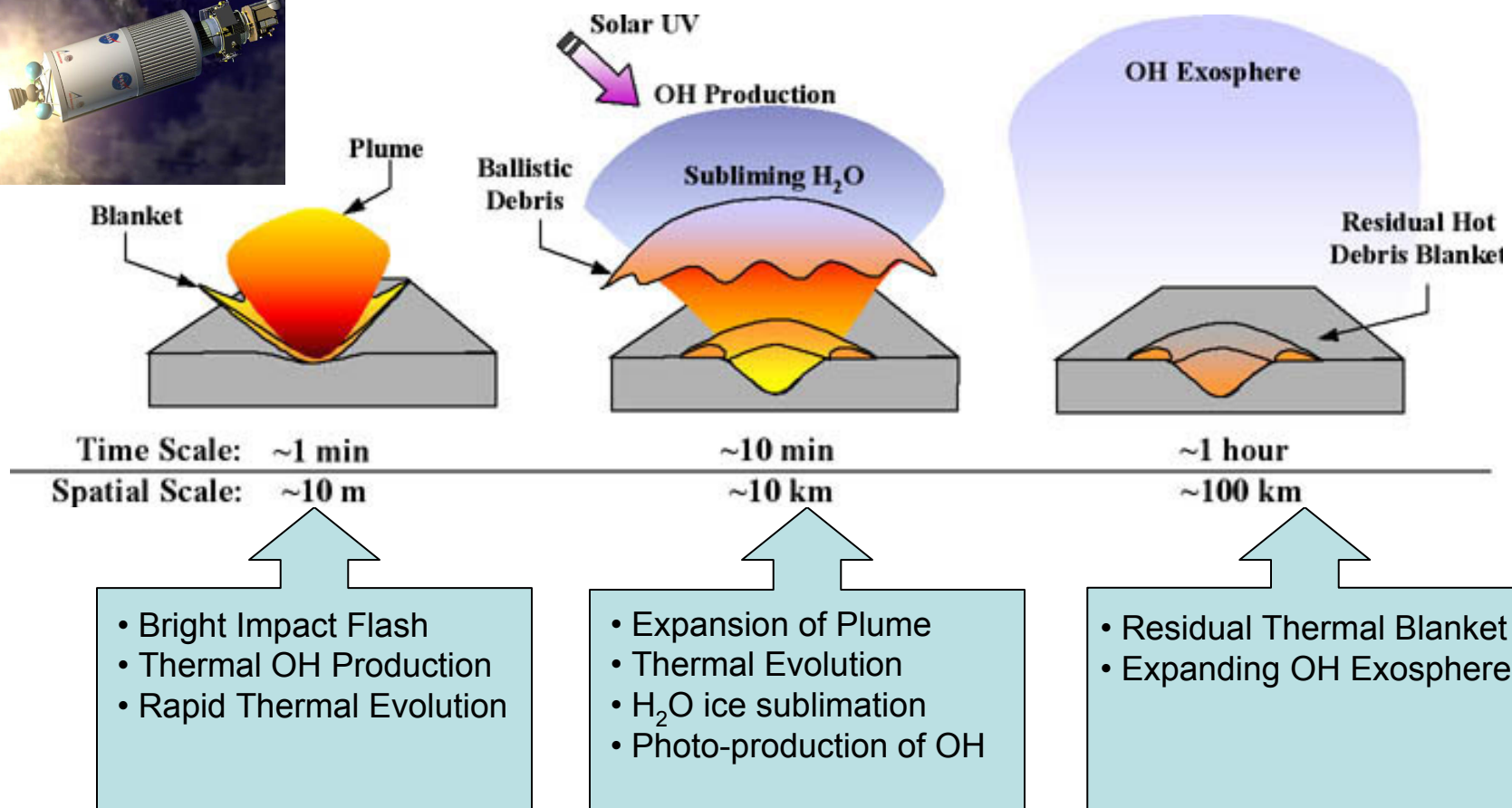
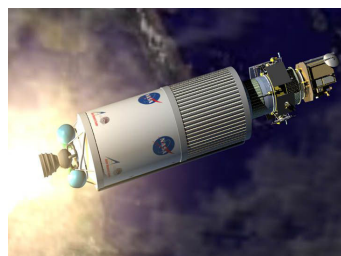


LRO Science Phase

- LRO Prime Science Mission
 - PSD funds the LRO extended mission (FY10 on)
 - Becomes the “Prime” Science mission phase
 - Team developing Level-1 science objectives
 - Upgrades to PDS to handle LRO data volumes
- LRO Participating Scientist program
 - Research using LRO instruments or data
 - Help define LRO’s prime science objectives
 - Received ~55 proposals; selected 24
 - Up to 4-yr awards, ~ \$ 80K/yr average
 - Expect this group to be part of the science team



Lunar Crater Observation and Sensing Satellite (LCROSS)



Ground-based, Earth-orbiting, and lunar-orbiting observatories will be able to observe and measure the impacts.
Expect impacts ~4 months after launch (early 2009)



GRAIL: Gravity and Interior Laboratory

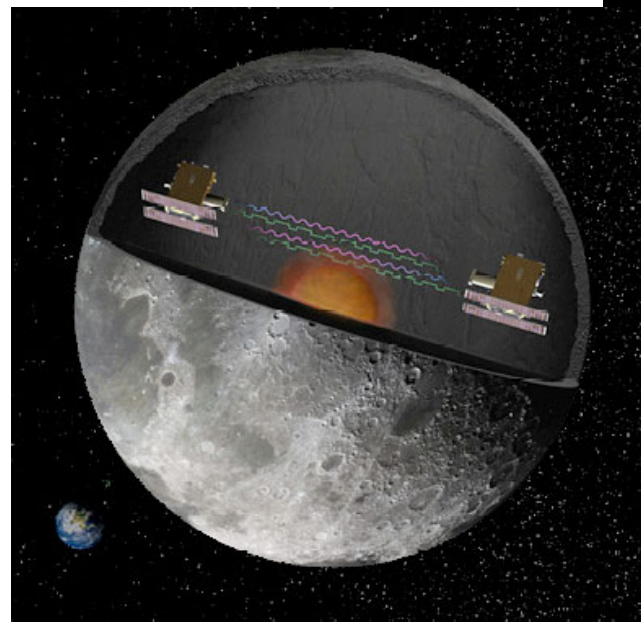


Newly Selected Discovery Mission In development

- **Team:** PI Maria T. Zuber (MIT), DPI David E. Smith (GSFC), PM David H. Lehman (JPL), PS Michael Watkins (JPL), Co-I's from JPL, GSFC, UA, Washington University, CIW/DTM, IPGP.

- **Goals:** Determine the structure of the lunar interior from crust to core; advance understanding of the thermal evolution of the Moon; extend knowledge gained from the Moon to the other terrestrial planets.

- **Mission:** Provide a global, high-accuracy ($<10\text{mGal}$), high-resolution (30km) lunar gravity map; build upon successful GRACE mission; adapt flight-proven LM XSS-11 bus to the dual spacecraft design.

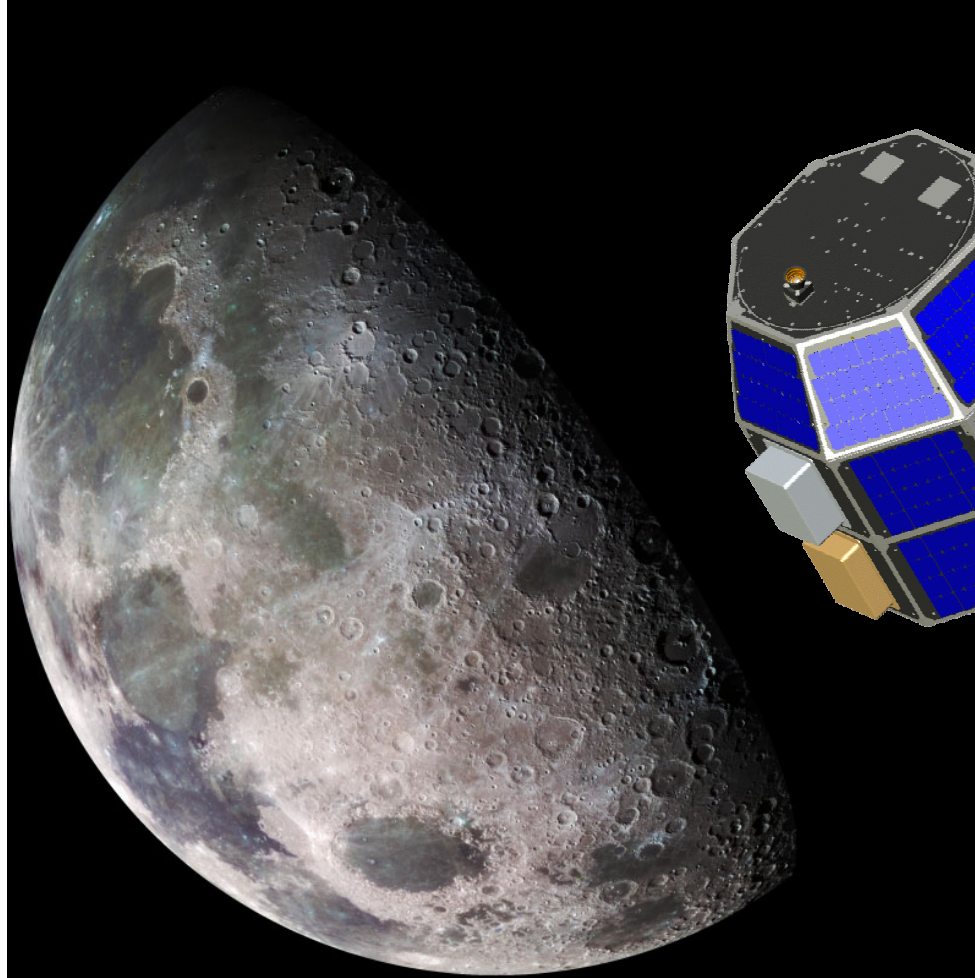


- **Instrument:** Ka-band ranging system determines the precise instantaneous relative range-rate of the two s/c; instrument is based on GRACE mission.

- **Flight:** 3–4 month low energy trans-lunar cruise; LOI maneuvers separated by 25 hours; 50-km, near-circular polar orbits, with s/c separation of 175-225 km; 90-day Science Phase.

Lunar Atmosphere & Dust Environment Explorer

LADEE: Examining the Lunar atmosphere/exosphere



SmallSat Orbiter

Provider: ARC / GSFC

\$80M LCC

Core Instruments:

Dust Counter

Neutral Mass Spectrometer

**NRC: Scientific Context for
Exploration of the Moon**

*Measuring the atmosphere before it is
perturbed by human activity*

*The lunar atmosphere may be dominated
by dust although its properties are not
well known.*

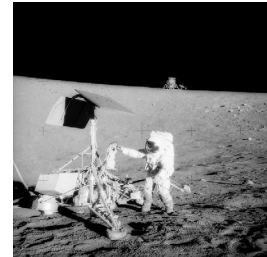
Launch in 2010 dual manifested with Grail



ILN Missions



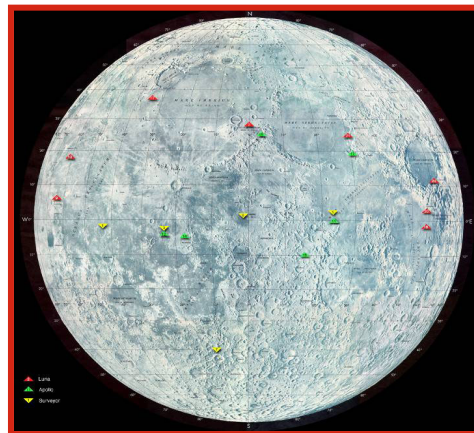
- SMD/ESMD initiating an effort to coordinate future lunar landed missions into an International Lunar Network (ILN)
 - NASA provides two ILN nodes, launched to the lunar poles (TBD), in 2013/2014
 - NASA (SOMD/ESMD) commits to a Lunar communications relay orbiter enabling lunar farside access for ILN nodes
 - Will consider a second pair of ILN nodes in 2016/2017
- The ILN is designed to emplace 6-8 stations on the lunar surface.
- Each ILN station would fly a core set of instrument types (e.g., seismic, laser retro-reflector, heat flow) requiring broad geographical distribution on the Moon
- Each ILN station could also include additional instruments as desired by the sponsoring space agency
 - Expect NASA instruments through Missions of Opportunity





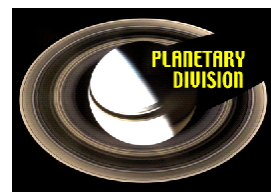
Next Steps

- Informational briefing to potential ILN partner Agencies at LPSC (Mar. 11th)
- Multi-Agency meeting at LPI (Mar. 12th)
 - Form ILN charter Working Group
- ILN Charter signed (~July 20th)
 - Form ILN landing site and core instrument definition working groups
- ILN core instrument agreement (~Dec. 2008)





Moon Mineralogy Mapper (M³)



Team

- PI: Dr. Carle Pieters, Brown University

Mission

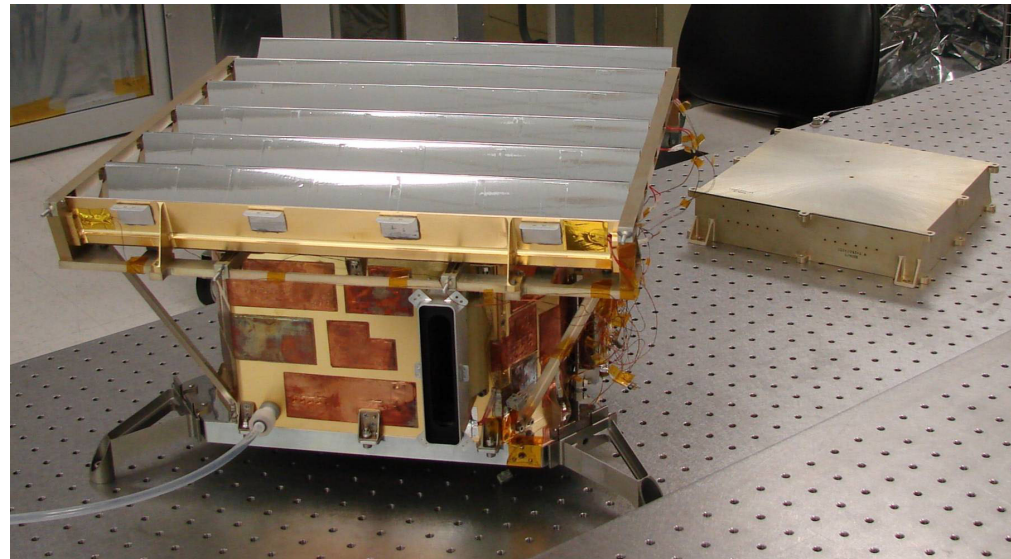
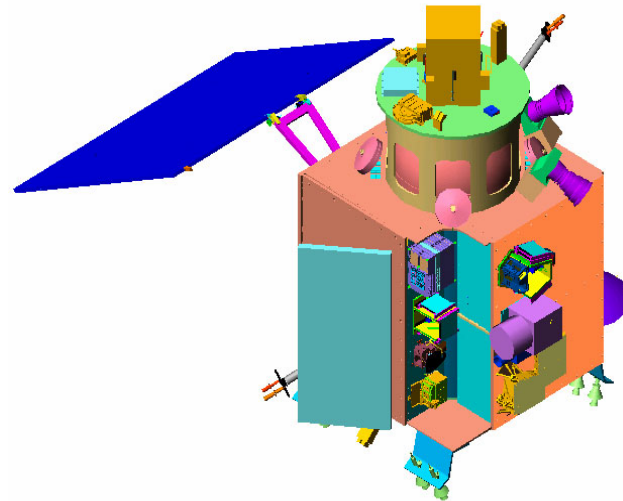
- M3 Instrument on Chandrayaan-1, India's first deep space mission.
- One of 11 instruments (5 of which are non-ISRO, 2 of which are from the US)
- Launch Date: Spring 2008 on ISRO's Polar Satellite LV
- Lunar Orbit: 100 km, polar
- Operational life: 2 years

Objectives

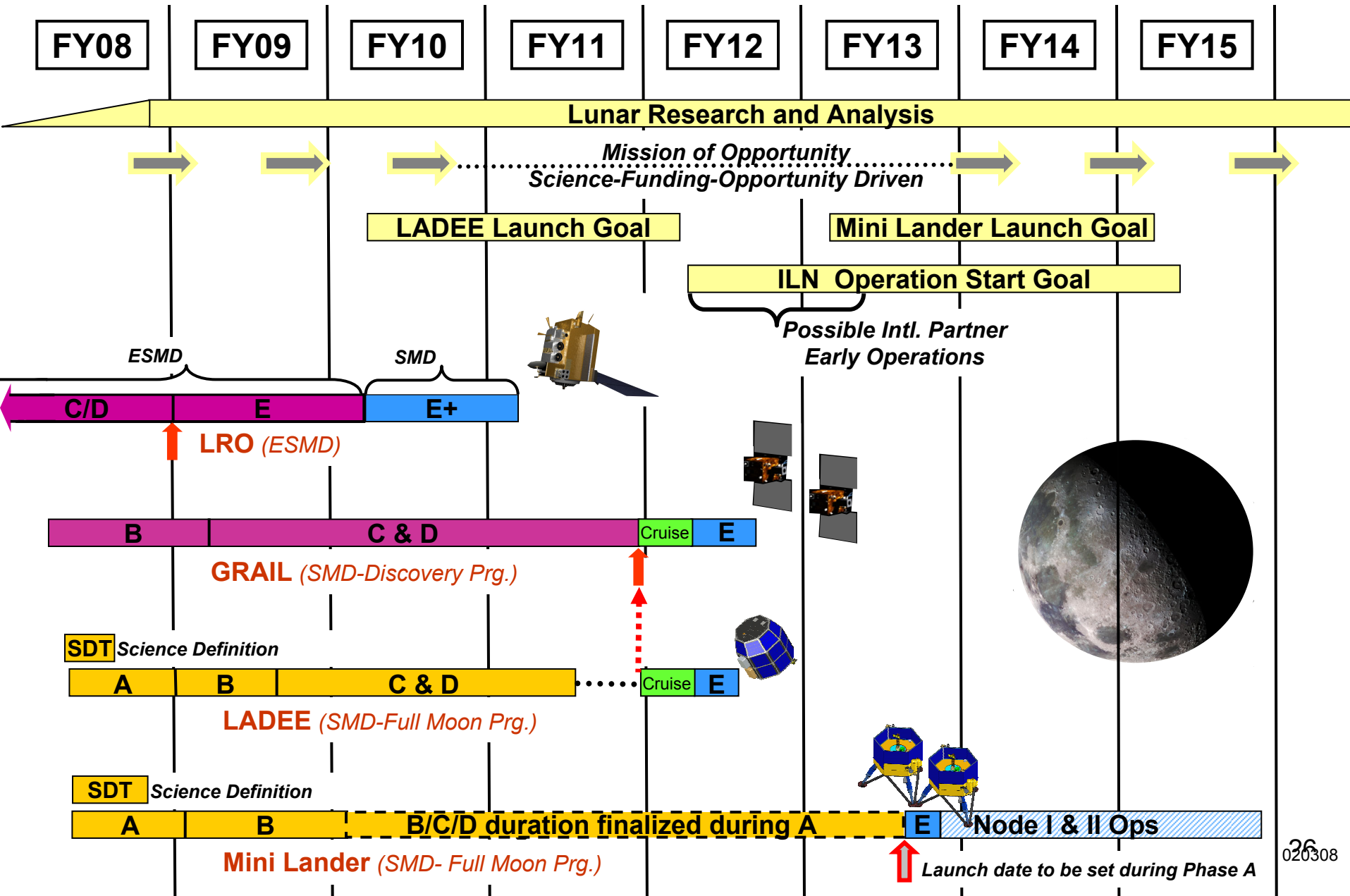
- Produce a Global Map of the Mineralogy content Lunar surface at 140m and 40 nm spectral resolution.
- Investigate specific targets at high spatial and spectral resolution
- Investigate the possibility of surface water ice at the lunar poles

Instrument

- A grating spectrometer, operating over the spectral region of 0.43 to 3 microns (Visible/Near IR)
- 2 Imaging Modes: Global (125 m res) and Targeted (63 m res)
- Instrument Delivery: January 2007



Lunar Missions Schedule





Focused R&A Activities

Instrument ▪ Opportunities



Lunar R&A



- Lunar Advanced Science & Exploration Research program (LASER)
 - Joint SMD/ESMD sponsored
 - Basic & Applied lunar research
 - Received ~160 received; selection in March
 - Up to 4-yr awards, ~ \$100K/yr average
- Moon and Mars Analog Mission Activities Program (MMAMA)
 - Established to enhance science integration into VSE architecture and technology development process
 - Small pilot program, 1-yr awards ~15-50K/yr average
 - Proposals due March 14, 2008



Technology and Instrumentation

- Lunar Sortie Science Opportunities (LSSO)
 - One-year concept studies (may be considered again in FY09)
 - Selected 14 studies at ~\$100K average/proposal
 - Spans geology, geophysics, physics, astronomy, & astrophysics
- Planetary Instrument Definition & Development Program (PIDDP)
 - Several lunar-focused instruments selected in 2007
 - Augmented in 2008 for add'l lunar instrument development
 - Up to 4-yr awards, ~\$250K/yr average
- Stand-Alone Mission of Opportunity Notification (SALMON)
 - Call for instruments will include Lunar missions
 - Draft to be released in February
- Discovery and Mars Scout Mission Concept Studies
 - New concepts using a GFE - Radioisotope Power System
 - Received 41 proposals - 14 Lunar mission concepts
 - Evaluation in February with selection in March

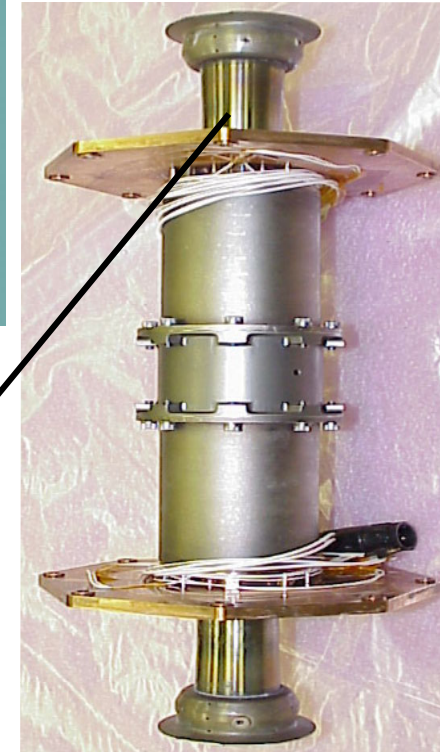
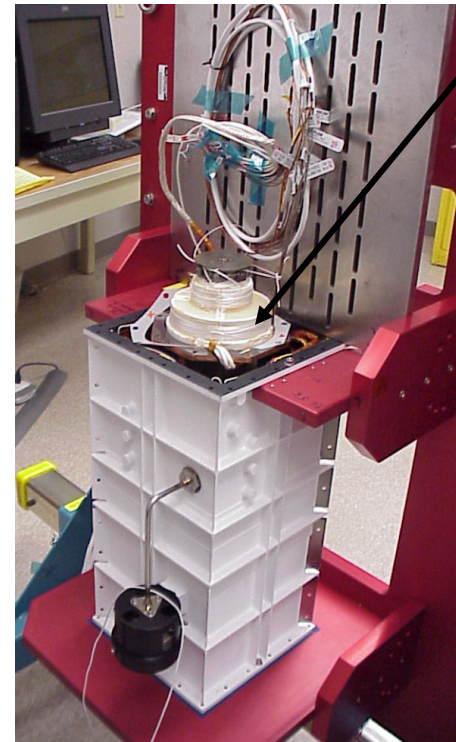
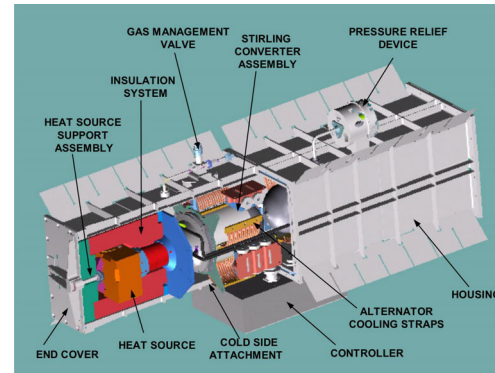


Advanced Stirling Radioisotope Generator Engineering Unit



Lockheed Martin/Sunpower

- Operation in space and on surface of atmosphere-bearing planets and moons
- Characteristics:
 - ≥ 14 year lifetime
 - Specific Power – > 7 We/kg
 - Nominal power : 140 We
 - Mass ~ 20 kg
 - System efficiency: $\sim 30\%$
 - 2 GPHS (“Pu²³⁸ Bricks”) modules
- Final wiring and connections for ASRG engineering unit underway
- Reliability to be demonstrated by the end of 2009



Paired converters with interconnect sleeve assembly

Outboard Housing and Paired ASC-Es



NASA Lunar Science Institute



NASA Lunar Science Institute



- Purpose:
 - Address basic lunar science, lunar sorties and outpost applications (e.g., lunar astronomy), exploration & science needs (e.g., lunar dust).
 - Quick response capability for VSE lunar science support
 - Grow and foster a Lunar science research community
 - Support NASA lunar flight missions
 - Train the next generation of lunar scientists, and communicate lunar science with educators and the public
- Modeled after the successful NASA Astrobiology Institute (NAI)
- Structure: Central node at AMES and distributed remote nodes
 - Provide for large focused research teams 8-15 FTEs each
 - Distributed nodes to be competed: Universities, other Centers, non-Profits, and international partners
 - Expect to fund 5-7 nodes at \$750k-\$2M/yr(SMD 4-5, ESMD 1-2)
- International Partnerships
 - Non-U.S. lunar science organizations can propose to become either Associate or Affiliate Members of the NLSI on a no-exchange-of-funds basis.
 - Requires long-term commitment with tangible and specific plans for scientific interaction that will produce results of mutual benefit



Schedule

- | | |
|-------|---|
| 10/07 | Alan Stern announces NLSI at DPS meeting
NLSI assigned to ARC for implementation |
| 11/07 | Chris McKay assigned organization of first LSC |
| 01/08 | David Morrison appointed Interim Director |
| 02/08 | Search begins for permanent Director |
-
- | | |
|-------|---|
| 03/08 | NLSI office opens in NASA Research Park
Website up and operating |
| 04/08 | CAN released for initial team selection |
| 07/08 | First Lunar Science Conference
Proposals for membership due |
| 08/08 | Lunar Science Roadmap workshop |
| 09/08 | Initial member teams selected |
| 10/08 | Begin funding for selected teams |





The NSLI Lunar Science Conference, co-sponsored by the NASA Lunar Science Institute and the Lunar and Planetary Institute, will be held July 22–24, 2008, at the NASA Ames Conference Center, adjacent to NASA Ames Research Center, Moffett Field, California.

The conference will review the state of knowledge of, and opportunities for, science:
Of the Moon: Study the nature and history of the Moon (including research on lunar samples) and thereby provide insights into the evolution of our solar system;

On the Moon: Investigate the effects of the lunar environment on terrestrial life and the equipment that supports lunar inhabitants, and the effect on robotic and human presence on lunar environment;

From the Moon: Use the Moon as a platform for performing scientific investigations, including observations of the Earth and other celestial phenomena that are uniquely enabled by being on the lunar surface.



LUNAR SCIENCE CONFERENCE

July 22–24, 2008 NASA AMES RESEARCH CENTER

The call for papers emphasizes the following science questions:

- How did the Moon form and how did its interior structure arise?
- How has the impact history of the Earth-Moon system been recorded on the lunar surface?
- How have volcanic process on the Moon been initiated over lunar history and how do the volcanic flows reflect the interior composition.
- How have solar processes and space weather altered the lunar surface over time and been recorded in the lunar regolith?
- How will the lunar environment (e.g., dust) affect surface operations and influence designs for living on the Moon?
- What are the environmental conditions and the volatile content of the lunar poles?
- How will increased human activities alter the lunar environment?
- How can life from Earth adapt to long stays on the Moon?
- How can the Moon be used as a platform to advance important science goals in astronomy, Earth observation, and basic physics?



LUNAR SCIENCE CONFERENCE

July 22–24, 2008 NASA AMES RESEARCH CENTER

Sessions will be structured to report on recent results and anticipate future opportunities for lunar science. Abstracts on elements of education and public outreach will be included to better understand how lunar exploration can be used to stimulate public interest in space exploration and improve science literacy.

An announcement with a call for abstracts, registration form, and logistical information will soon be posted at <http://www.lpi.usra.edu>

For more information on the NLSI Lunar Science Conference contact:

Science

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Abstract submission

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ROBOTIC LUNAR MISSION OBJECTIVES



Science Definition and Execution (HQ: SMD)

- Strategic Planning
- Research & Analysis Administration
- Program Direction
- Robotic Science Missions
 - Gravity Recovery And Interior Laboratory (GRAIL)
 - Lunar Atmosphere Dust Environment Explorer (LADEE)
 - International Lunar Network (ILN) Landers
 - International Robotic Science Instruments

Operations (HQ: SOMD)

- Operations Systems and Demonstrations, such as Communications

The Lunar Environment Characterization (HQ: ESMD)

- Support human Lunar landing design
- Support for Lunar surface mobility and habitability
- Cooperation with future mission of opportunity
 - Fly instruments for needed data
 - Technology demonstrations
- Robotic Missions
 - Lunar Reconnaissance Orbiter (LRO)
 - Lunar Crater Observation and Sensing Satellite (LCROSS)



ROBOTIC LUNAR WORK ASSIGNMENTS



Marshall Space Flight Center

- Lunar Science Program (to be combined with LPRP by 2010)
 - Flight Mission Management (MMM, GRAIL, LADEE & ILN Landers)
- Lunar Pre-Cursor Robotic Program (to be combined with LSP by 2010)
 - Flight Mission Management (LRO & LCROSS)
- Lunar mini-landers; first pair of spacecraft to launch by 2014 as part of an International Lunar Net.
- Lunar Mapping Project; Begins in FY 08

Ames Research Center

- NASA Lunar Science Institute (NLSI); begins March 2008
 - Cooperative Science Research & Analysis Administration
- LCROSS impactor; launches late 2008 with LRO.
- LADEE lunar orbiter; launches 2011 with GRAIL.

Goddard Space Flight Center

- Lunar Reconnaissance Orbiter (LRO) mission; launches late 2008
- LADEE lunar orbiter systems in partnership with Ames; launches 2011.

Applied Physics Lab

- Lunar mini-lander systems or payload to support MSFC; a pair of spacecraft to launch by 2014.
- Mini-RF systems (instrument on ISRO lunar Chandrayaan orbiter); launches mid-2008 and technology demonstration on LRO; launches late 2008

Jet Propulsion Lab

- GRAIL (Discovery mission); launches 2011.
- Moon Mineralogy Mapper (instrument on ISRO lunar Chandrayaan orbiter); launches mid-2008.

A composite image of the solar system. In the upper right, Earth is visible as a blue and white sphere. In the center, a large, bright orange sun or star is partially obscured by a large, reddish-orange planet (Mars) in the foreground. The background is a dark space filled with stars and nebulae. In the lower left, a Mars rover is shown on the reddish-brown surface of Mars.

NASA's Planetary Science

Advance scientific knowledge of the origin and history of the solar system, the potential for life elsewhere, and the hazards and resources present as humans explore space

“Flyby, Orbit, Land, Rove, and Return Samples”



LSSO Year 1 Awards

PI Name	Company name	Title
William Banerdt	Jet Propulsion Laboratory	Concept Study for an Autonomous Lunar Geophysical Experiment Package (ALGEP)
Daniel Glavin	NASA Goddard Space Flight Center	Volatile Analysis by Pyrolysis of Regolith (VAPoR) on the Moon using Mass Spectrometry
Donald Hassler	Southwest Research Institute	Lunar Radiation Environment and Regolith Shielding Experiment
Jerome Johnson	USA ERDC-CRREL	Lunar Suitcase Science: A Lunar Regolith Characterization Kit (LROCK)
Christian Grund	Ball Aerospace & Technologies Corp.	Autonomous Lunar Dust Observer
Patrick Taylor	NASA Goddard Space Flight Center	Seismology and Heat flow instrument package for Lunar Science and Hazards
Slava Turyshev	Jet Propulsion Laboratory	Lunar Laser Transponder and Retroreflector Science



LSSO Year 1 Awards (cont.)

PI Name	Company name	Title
Michael Collier	NASA Goddard Space Flight Center	Lunar-Based Soft X-ray Science
Douglas Currie	University of Maryland, College Park	A Lunar Laser Ranging Array for the 21st Century
* Everett Gibson	NASA Johnson Space Center	Beagle to the Moon in Search of Hydrogen, Water and Volatiles
Dayton Jones	Jet Propulsion Laboratory	Lunar Array Precursor Station (LAPS)
Joseph Lazio	Naval Research Laboratory	Radio Observatory for Lunar Sortie Science
Stephen Merkowitz	NASA Goddard Space Flight Center	Precision Lunar Laser Ranging
Edward Rhodes	Jet Propulsion Laboratory	Development of a Solar Disturbance Warning System Using Lunar-Based Observations of Solar Subsurface Weather

* International participation